Northern Power Systems Cold Temperature Stud Testing

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ABSTRACT

Northern Power Systems Cold Temperature Stud Testing. Steven Ramey (West Virginia University Institute of Technology, Montgomery, WV, USA 25304). Walt Musial (National Renewable Energy Laboratory, Golden, Co, 80401).

Electricity produced by wind turbines is currently becoming economical in many remote areas where centralized conventional power plants are not feasible. Large portions of these remote areas are located in the arctic regions of the world. Future exploration of the planet Mars will also require energy generation on the planet itself. With funding from NASA, Northern Power Systems (NPS) is currently designing a cold temperature wind turbine that would operate in the environments referred to above. The National Wind Technology Center is assisting NPS in testing the strength of existing bonded blade root studs in a –50 degree F. In order to perform these tests a cold temperature box had to be design and built that would be compatible with the existing test stand and equipment used for earlier root stud tests performed at room temperature. The temperature of the box had to be controllable so that the temperature of the samples could be maintained at –50 F +/- 2 degrees. Furthermore, the system had to meet certain safety guidelines. The cooling system designed for this project consisted of a cryogenic liquid container with liquid nitrogen, an insulated box, piping required for supply and vaporization, temperature/flow control system, and pressure control. Future goals will be to perform the axial static and fatigue tests on four different specimens and develop a plan for additional testing of specimens.

Research Category (Please Circle)

ERULF: Physics Chemistry Biology Engineering Computer Science Other ________

CCI: Biotechnology Environmental Science Computing

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Introduction

The cost of producing electricity from wind has dropped tremendously over the past twenty years. In 1981 the cost of wind power plant electricity was $0.30/kWh. Today it is about $0.05/kWh. Although the cost of producing electricity from wind has dropped tremendously over the last twenty years, it is still cheaper to produce electricity from fossil fuels ($0.03 to $0.04/kWh) (6,1). However, in many remote areas it is not feasible to build the large power plants needed to convert coal and gas to electricity. Therefore, alternative sources of electricity generation are needed for these areas and wind energy often provides a very economical solution.

Kotzebue, Alaska is a remote Eskimo-trading center located at the northwestern end of Baldwin Peninsula, on Kotzebue Sound. Electricity for this area is primarily produced using diesel generators, which are relatively expensive to operate and produce a lot of harmful emissions. Another problem with diesel fuel is that it can only be shipped by sea during the summer months. Therefore, large storage tanks are needed to store the diesel fuel. Furthermore, the government currently provides subsidies in order to lower the cost of diesel fuel. Soon the government subsidies will end and the cost of producing electricity from diesel fuel will increase five times (2,1). However, Kotzebue has an excellent wind resource that could be harnessed and used to generate electricity using modern wind turbines. Furthermore, current financial and environmental issues make wind energy a very economical and attractive electricity source for Kotzebue. The challenge is to design a wind turbine suitable to operate in the low temperatures and high winds of this harsh arctic region.

A more exotic location where wind turbines could prove to be an economical solution is on the planet Mars. NASA is very interested in the future exploration of the red planet and hopes to have a base station there in the near future (25-50 years). It will not be feasible to transport fuel from Earth to meet the energy needs of such a project. Therefore, NASA is looking to wind as a possible "on site" energy source. Wind could be utilized in a solar/wind hybrid system to power a research station. As with Kotzebue, Alaska, a wind turbine installed on Mars would have to be able to withstand extremely cold temperatures.

With funding from NASA and a possible market in Alaska, Northern Power Systems (NPS) is in the process of designing a cold weather turbine capable of withstanding the harsh environments of Kotzebue, Alaska and Mars. In addition, NPS feels that the cold weather turbine product that emerges from this research will address a viable commercial market consisting of the hundreds of remote villages in Alaska and Canada that rely on expensive diesel fuel shipments for their power generation needs. In order to insure that their design is capable of withstanding the extreme cold, NPS, along with several contractors and the National Renewable Energy Laboratory, are currently performing a series of cold temperature tests on various wind turbine components.

By working with private businesses within the wind industry, the National Wind Technology Center (NWTC) of the National Renewable Energy Laboratory (NREL) helps to promote the use of wind energy. The mission of the Structural Testing division of NWTC is to develop and perform tests that accelerate or exaggerate catastrophic events that may happen to wind turbines in the field. The data collected from such tests is used by designers to develop stronger, more reliable wind turbines.

In support of NPS's design process for a cold weather wind turbine, the Structural Testing Division of NWTC will be providing a series of cold temperature structural tests on various components being considered for the cold weather turbine. One such test is to baseline the strength of existing 7.5" long ERS-0100 bonded blade root studs at cold temperatures to determine if an improved design is needed to meet required static and fatigue strength margins.

In the fall of 1999, six tests were performed at NREL on bonded blade root studs with the same geometry, but at room temperature. These new tests are design for direct comparison with the 1999 tests. A test plan was initially prepared that covered the basic elements for axial static and fatigue testing of the NPS root stud specimens at temperatures representative of the Alaskan climate. The objectives of the NPS cold temperature root/blade tests were the following:

- Determine the static and fatigue strength of the bonded blade root stud specimens at temperatures of –50 degrees F
- Compare the results to baseline tests conducted at room temperature and determine whether a new root stud design is needed to meet strength requirements
- Determine the direction and scope of Phase II testing

Project Goal

The goal of this project was to design and build a cold temperature box that would be compatible with the existing test stand and equipment used for the earlier root stud tests performed at room temperature. The temperature of the box had to be controllable so that the temperature of the samples could be maintained at –50 F +/- 2 degrees. Furthermore, the system had to meet certain safety guidelines.

Test Specimens

The root studs to be tested are bonded into cavities in the blade laminate with an epoxy adhesive (see figure 1). The bonded blade root stud specimens being tested are approximately four inches in diameter by 32 inches long. The specimens have a double-ended symmetrical design so that they are easily mounted in the test load frame using button head grips. This design allows the inspection of a failed stud along with a stud taken almost to failure. This design also allows for the same test frame attachments to be used on both ends of the test specimens. Adapter ends, which mate to the root of the specimens, fit within the button head grips. The adapters are hollow to allow a ¾" capscrew to engage the female threaded stud bonded into the end of each specimen.

Existing Test Setup

The axial tests will be performed at the NWTC's Structural Test Facility on the 100-kip load frame located in the highbay of building 251. The load frame is equipped with a double-ended hydraulic actuator rated at a maximum load of 100 kip. The actuator has a maximum stroke of 6 inches and is driven by a 75 GPM hydraulic pump.

To efficiently mate the double-ended stud test specimens to the load frame using standard grips, a pair of button head adapters developed by NREL will be used as shown schematically in Figure 2. The adapter has a hole down its center and has a recess in the button head. This allows a high strength ¾" capscrew to be used to attach the grips to each end of the test specimens. With this configuration, real blade studs with ¾" female threaded connections can be used instead of producing special studs with expensive, integral button heads. Also, the adapters can be reused for similar tests. There is a risk of bolt failure with this setup since it is not as strong as an integral button head. However, if the load is high enough to break the high strength bolts, a high level of stud strength will have already been demonstrated.

The load frame will be controlled from the Building 251 control room using the existing MTS Flextest IIM control system. The system will be operated under load control mode. Static test load rates will be set at 10,000 lb/min. Fatigue test load rates will be set at 3-4 cycles/sec. The test technician will determine the final test frequency.

NREL's Blade Structural Testing Real-Time Acquisition Interface Network (BSTRAIN) will be used for acquiring the static and fatigue test data. Figure 3 in the appendix shows a schematic of the BSTRAIN system taken from the manual [1,2]. The SCXI modules will be configured with the low pass frequency set at 4 Hz for the static tests and 10,000 Hz for the fatigue tests. The output from the controllers will be 0 to 10 VDC. Maximum and minimum (peak and valley) data will be recorded during the fatigue test, with data sampled at 100 KS/s. Channel sampling rate will be set at 5 Hz for the static tests and 120-Hz for the fatigue tests. Fatigue test data collection will only save data for the peaks and valleys. Channels 0 and 1 will be displacement and load respectively. Channels 4-9 will be used for the 6 temperature measurements.

Cold Temperature Testing

The target temperature for testing these specimens is –50 degrees F. Due to the thermal mass of the specimens it was believed that it would take a significant amount of time to cool the specimens down to this temperature. Another potential challenge is that the grippers would conduct heat from outside the chamber to the root connections. The goal was to initially cool the specimens down to the point where the roots would be held uniformly at –50 degrees F, even if the ambient temperature within the box or the blade material was cooler than –50 degrees F. The anticipation was that some temperature difference might have to be tolerated due to the conduction of heat from the grips into the specimen. The goal was to develop a uniform temperature between the stud and the fiberglass to within +/- 2 degrees F.

Dry ice (solid CO_2) will be used initially inside the chamber for an extended period in order to bring the temperature of the specimen down to –50 degrees F. Once the temperature is brought down using the dry ice, a liquid nitrogen delivery control system will be used to maintain the samples more precisely at a given temperature.

The cooling system designed for this project consists of a cryogenic liquid container with liquid nitrogen, an insulated box, piping required for supply and vaporization, temperature/flow control system, and pressure control. Since it is readily available, relatively inexpensive, and has a low boiling temperature, liquid nitrogen was chosen as the refrigerant for the cold temperature box. The cryogenic container used for storing the liquid nitrogen is a 160 liter tank with both liquid and gas withdrawal valves. It is constructed like a vacuum bottle and is designed to keep heat away from the liquid contained in the inner vessel. Care has to be taken when working with liquid nitrogen due its low temperature and its asphyxiating potential as it expands to gas. Liquid nitrogen has an expansion ration of approximately 700 to 1, which means that it can displace a lot of oxygen when it is allowed to expand.

In order to cool the specimens to –50 degrees F, a cold temperature box was constructed which will enclose the test specimens while fitting within the existing load frame. The chamber is constructed of a wooden frame covered with ½” plywood. The chamber is insulated with 6” of extruded polystyrofoam insulation board. This gives the chamber an R-value of 30. The door of the chamber, which makes up the front of the box, is removable so that the cold box can slide over the installed test specimens and baffles as depicted in figure 4. The door contains two small windows to allow inspection of the roots during testing. The windows are constructed of three panes of ½” Plexiglas.

Before installing the test samples, two baffles are installed onto the upper grips, one at each end of the specimen. Once the baffles are in place, the test specimen is loaded into the test stand using the grippers. With the door removed, the cold temperature chamber will slide onto the baffles such that the baffles will form the top and bottom of the chamber. Then the chamber will be bolted to the base of the test stand and the door will be secured to the chamber.

Liquid nitrogen is delivered to a vaporizing coil inside the cold temperature box by copper lines covered with foam insulation. Copper lines were used because they are rated for cryogenic temperatures. Once the liquid nitrogen flows into the box, it is allowed to expand to its gaseous state within the vaporizing coil. The coil consists of ¾” copper pipe (uninsulated) routed into a series of loops within the box. Since liquid nitrogen boils at –320 degrees F and the temperature inside the box is held close to –50 degrees F, the liquid nitrogen begins to evaporate inside the coil. It takes a lot of energy to vaporize a liquid; therefore heat is pulled from within the insulated box which cools the box.

A JC Control SLV 100 solenoid valve connected to two Omega CNI series 1600 on/off temperature controllers will control the flow of liquid nitrogen into the chamber. Two type T thermocouples attached to the root/button head connection at each end of the specimen will provide feedback to the system. If the temperature is greater than a given level at either of these locations, then the solenoid valve will energize allowing liquid nitrogen to flow into the vaporizer within the chamber. When the temperature falls below a given set point, the solenoid valve will close and the liquid nitrogen will stop flowing.

Due to the high expansion rate of liquid nitrogen to gas, a pressure relief had to be incorporated in any section of the system's piping where liquid nitrogen could collect between two valves. For this system a 22-psig relief valve was installed between the liquid valve of the tank and the solenoid valve.

Discussion of Future Project Goals

The next step will be for the cold temperature system to pass the readiness verification performed by Mike Stewart of the Environmental Health and Safety Office. Once the cold temperature box system has passed the readiness verification the actual testing of the root studs can commence. Phase one will include a total of four tests performed on four different test specimens. The results of these tests will guide future testing.

The first test specimen will tested for static tensile strength using a linear ramp load. The goal is to choose a ramp load, which would cause the specimen to fail around 5 minutes. A ramp rate of 10,000 lbs/min will be used since the failure rate is expected to be less than 70,000 lbs under cold conditions.

The second specimen will be used for tension fatigue testing at R = 0.1 for the cold condition where R is defined as the load amplitude ratio F_{min}/F_{max}. The cycle target is in the 10,000 to 50,000 range with the test load being determined from the results of the static tension test. NPS consultant Mike Zuteck will make this decision with concurrence from NREL and NPS staff.

The third stud specimen is to be used for R = -1.0 fully reversed fatigue in the cold condition. As with the tension fatigue test, the cycle range is 10,000 to 50,000. The test load will be determined based on the combined results of the first two tests.

The final test specimen will be used to obtain a fatigue curve slope for either tension or fully reversed fatigue. The results of the fatigue analysis of the blade root under the first three loading cases will determine whether the test will be tension or fully reversed fatigue. In other words, whichever loading is most critical to blade life will be studied. The loading will depend on which test is performed, and whether the perceived need is greater for the high cycle or low cycle end of the fatigue curve.

The above tests are all subject to change. They have been arranged in such a way that completed tests can guide the loading for subsequent tests. Also, the most important tests will be performed first. Therefore, if a test is lost on account of unforeseeable problems, another specimen can be shifted into that test as a replacement. In which case, the last test would be forfeited.

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Appendices

Figure 1. Root stud specimen removed from blade laminate.

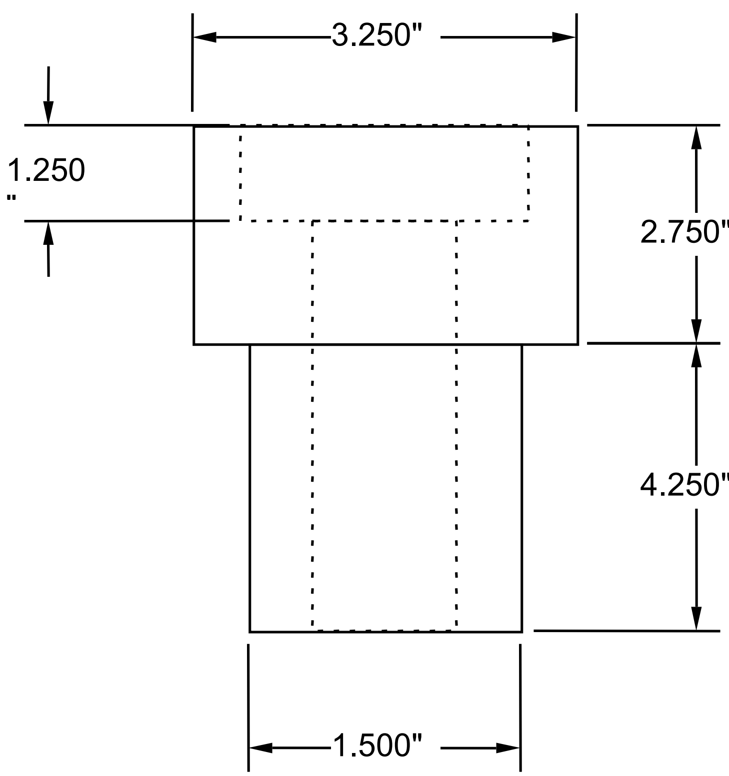

Figure 2. Button head adapter for 7.5" Stud Tests.

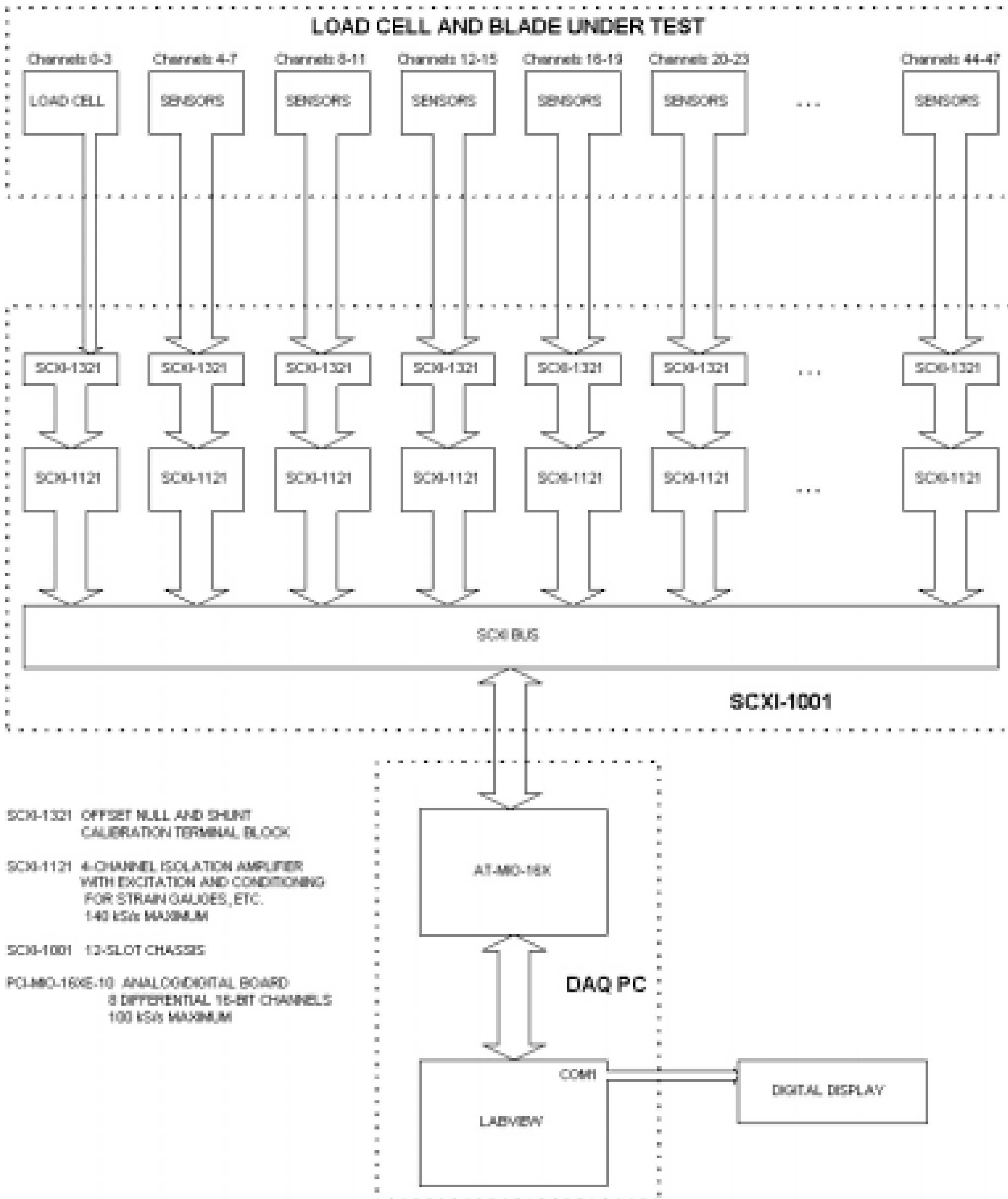

Figure 3. BSTRAIN Data Acquisition Schematic.

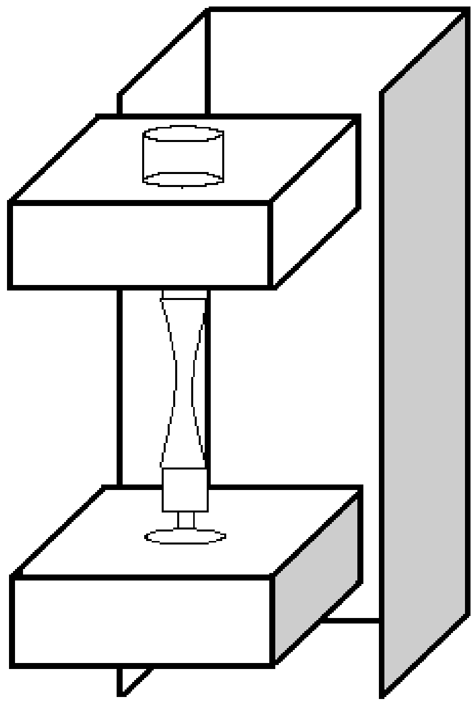

Figure 4. Diagram showing baffles installed over grippers before the chamber is slid into

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